STATUS AND DESIGN CHARACTERISTICS OF THE BCR/OCR BI-GAS PILOT PLANT

By

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I. INTRODUCTION

Research and development was initiated in 1965 on the generation of data required for the design of a pilot plant for the production of high-Btu pipeline gas based on the concept of two-stage super-pressure entrained gasification of coal. Experimental work on the program has progressed successively through three levels of scale-up and has now reached the point where operation of a fully integrated coal-to-pipeline gas pilot plant is considered to be the next logical step in the development of the process.

Initial experiments were conducted in rocking autoclaves using 5-gram charges of coal. Resultant data confirmed the basic assumption that a high yield of methane could be obtained directly from coal by reaction with steam at elevated temperatures and pressures.(1)*** Flow experiments in an externally-heated reactor confirmed the assumption that higher methane yields could be obtained from coal entrained in steam-synthesis gas mixtures at short residence times.(1) Recent work in an internally-fired 100 lb/hr flow system has further confirmed the basic principle and advantages of the two-stage super-pressure concept, and has provided design data for the integral two-stage gasifier.(2)

This paper presents the design characteristics of a fully integrated coal-to-pipeline gas pilot plant based on a 5 ton/hr two-stage, super-pressure, entrained oxygen-blown gasifier, otherwise designated as the BCR/OCR BI-GAS PROCESS.

II. BASIC PRINCIPLES AND ADVANTAGES OF THE BI-GAS PROCESS

A. Basic Principle of BI-GAS Process

In the two-stage super-pressure gasification process(3), fresh pulverized coal is introduced into the upper section (Stage 2) of the

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*** Numbers in parenthesis indicate references listed under "Literature Cited."

gasifier at pressures in the range of 70 to 100 atm. (See Figure 1.) Here, the coal comes in contact with a rising stream of hot synthesis gas produced in the lower section (Stage 1) and is partially converted into methane and more synthesis gas.

The residual char entrained in the raw product gas is swept upward and out of the gasifier. The char is separated from the product gas stream and recycled to the lower section (Stage 1) of the gasifier.

In the lower section, the char is completely gasified under slagging conditions with oxygen and steam, producing both the synthesis gas and the heat required in the upper section (Stage 2) for the partial gasification of the fresh coal.

B. Status of Development

The research and development to date has been directed primarily toward development of the technology of Stage 2 and optimization of operating conditions for production of a gas suitable for conversion to high-Btu pipeline gas by catalytic methanation. Through laboratory-scale studies and process and equipment development, design data for Stage 2 is now available. The technology of Stage 1, while not complete, has been well advanced by others and is considered adequate for design of a pilot-scale unit. Construction and operation of an integral two-stage gasifier is now considered the next step in development of the BI-GAS process.

C. Advantages of Two-stage Gasification

When the two-stage gasifier is operated on oxygen at system pressures of 1,000 psi or higher, the resultant raw gas is an excellent feedstock for upgrading to substitute natural gas.

When the gasifier is operated on air at moderate system pressures, a gas is produced which may be readily desulfurized and cleaned to yield a pollution-free fuel gas with a heating value of about 175 Btu/scf.

The two-stage, oxygen-blown, super-pressure gasifier offers several advantages in the production of substitute natural gas. A high yield of methane is obtained directly from coal and subsequent processing of the output gas is minimized. Because it is an entrained rather than a fixed or fluidized-bed system, all types of coal should be amenable without prior treatment for use in this gasifier. All the feed coal is consumed in the process; principal by-products are slag for disposal and sulfur for sale. The two-stage gasifier, being an integral unit, is relatively simple in design and amenable to scale-up to most any size. Also, the conditions in Stage 2 are such that no tar and oils are formed in the gasification process.

III. DESCRIPTION OF BI-GAS PILOT PLANT

For the past two years, planning has been underway for the further development of two-stage gasification. The plans include a much broader concept than the erection and operation of a pilot-scale gasifier. Inasmuch as the equipment, personnel, and other facilities necessary for the pilot testing of the BCR two-stage process will be usable in the solution of problems related to other gasification processes under development, it appears prudent that a broader view should be taken in planning of pilot-plant research.

Further stimulating this concept is the growing interest in the development of a new approach to power generation incorporating coal gasification at the power station; this approach would use an air-blown rather than an oxygen-blown gasifier, followed by large high-temperature gas turbines.

Early discussions with the Office of Coal Research resulted in the concept of a multipurpose research integrated facility, and a technical evaluation and cost estimate of such an integrated research facility was made with the assistance of Koppers Company, Inc.[4]

The research facility as currently planned will ultimately embody alternate systems for each of the major unit operations in the conversion of run-of-mine coal, or char, to high-Btu pipeline gas; to sulfur-free, low-Btu fuel gas; to industrial gases; and to MHD fuel gas. Three types of gasification units will be provided: an air-blown, medium-pressure, two-stage gasifier; an oxygen-blown, super-pressure, two-stage gasifier; and a low-pressure, multi-stage, fluidized-bed gasifier.

The initial pilot plant is now being designed for the multipurpose research pilot plant facility (MPRF); it is based on the oxygen-blown version of the two-stage gasifier and will include all facilities needed for converting coal into high-Btu pipeline-quality gas.(5) In addition to the basic gasifier, the system would include facilities for: coal crushing, sizing, and drying; high-pressure coal feeding system; dust and heat recovery; CO-shift; acid gas removal; and methanation. (See Figure 2.) Space will be provided for future installation of special beneficiation equipment for preparation of enriched gasifier feedstock.

A. Coal Beneficiation, Storage, and Handling

Initial operations of the 5 ton/hr pilot plant will be confined to the testing of washed coals. Prepared coals, with an approximate size consist of 1-1/2 inch by 0, will be delivered to the plant. However, the plant layout will provide for the future addition of coal beneficiation facilities to permit the receiving and processing of run-of-mine coals. Figure 3 is a schematic diagram of these facilities.

The washed coals for the early test work will be received via truck hopper and transferred to two 450-ton storage bins by a conveyor system, equipped with belt scales, tramp iron magnet, and automatic sampler. Similarly, run-of-mine coal may be unloaded at the truck hopper, conveyed to a primary crusher and thence to storage, or crushed coal may be delivered directly to the final crushing and screening station before the beneficiation plant.

Laboratory studies have indicated that by proper choice and beneficiation of the gasifier feedstock, increased yields of methane may be expected in Stage 2 of the gasifier. These studies, aimed at concentrating the gas-rich macerals, are being continued in an effort to develop systems more effective than those currently available. The proposed initial coal beneficiation system shown schematically in Figure 4 will include the following circuits;

air flow tables for treating 3/4 inch x 0, 38 inch x 0, or 1/4 inch x 0 coals;

Deister tables for treating 3/8 inch x 28M or 1/4 inch x 28M coals;

heavy media cyclones for treating 3/4 inch x 28M coal or 1/2 inch x 28M and,

flotation cells for treating the minus 28 mesh coal.

The coals to be tested in the 5 ton/hr pilot plant will range in rank from lignite to high volatile bituminous. The tentative program includes the testing of: Pittsburgh Seam; Illinois No. 6 Seam, or West Kentucky No. 11 Seam; Elkol Seam from Wyoming; and, North Dakota Lignite. In addition, it is planned to conduct tests on chars produced from other coal conversion processes now under development.

The system for handling and preparing the washed coal for feed to the gasifier is shown in Figure 5. The coal is delivered from the 450-ton storage bins by means of weigh feeders and conveyor belt to a combination dryer and pulverizer equipped with a classifier for returning oversize coal to the pulverizer and with primary and secondary separators for receiving the pulverized coal. The dry coal, pulverized to approximately 70 percent minus 200 mesh, is transferred from these receivers by screw conveyor to a pulverized coal storage bin.

The system also provides for the handling of flux materials. The flux may be mixed with the coal and fed to Stage 2 of the gasifier or the flux may be fed separately to Stage 1.

B. Coal Feeding

A major mechanical problem associated with processes designed for the total gasification of solid fuels in suspension is the injection of the pulverized fuel into the systems at a uniform feed rate at pressures of 50 to 100 atmospheres. Since the conception of high pressure oxygen gasification of coal, with its apparent advantages over atmospheric pressure operation for the production of pipeline gas, considerable effort has been devoted to developing feeding systems for high-pressure operation. Feed systems that have been, or currently are, under development include fluidized feeders, lock-hopper systems, slurry systems, high-pressure jet feeders, and various designs of table, rotary, and screw feeders.

The slurry feed system would appear to provide the least complicated means of transport and of obtaining a uniform feed rate providing the ratio of solids to liquid is constant. The use of water as the vehicle introduces a thermal disadvantage and creates a problem in that the amount of water required for a pumpable slurry is in excess of the water required for the steam reactant. Attempts to flash off the excess steam just prior to entry to the gasifier reactant nozzles have met with little success to date. The use of oil as the vehicle would eliminate these problems associated with the water slurry and, of course, would result in increased gas production.

To overcome the disadvantages of the lock-hopper and slurry systems, BCR conceived a design of a piston type feeder which was confirmed by laboratory experiments. A nominal 600 lb/hr prototype unit incorporating certain modifications was purchased for test operation.

As shown in Figure 6, the piston coal feeder has two main operating sections, a low-pressure section and a high-pressure section. In the low pressure section, pulverized coal is transferred pneumatically from a storage tank to the weigh tank, F-1, using an inert gas as the transport medium. From the weigh tank, F-1, at atmospheric pressure, the coal flows by gravity through a pneumatically operated ball valve into a low pressure injector vessel, F-2. The injector vessel, F-2, is pressurized with recycle product gas to about 90 psi.

In the high pressure section, while the piston is in the raised position, the coal-gas mixture in the F-2 vessel is vented into the high pressure piston injector vessel, F-3. The ball valve between the F-2 and F-3 vessels is then closed and the F-3 vessel is pressurized to about 100 lb above that of a high-pressure receiver, F-4. The valve between the F-3 vessel and the F-4 vessel is then opened; by so doing, the coal plus gas is allowed to flow into the receiver vessel. Hydraulic pressure lowers the specially designed piston and completes the transfer of the residual coal-gas charge into the high-pressure receiver. The valve between the two vessels is closed, the small quantity of high pressure gas remaining in the injector vessel is vented to a gas holder, and the piston is returned to its original position by means of a hydraulically operated lift rod. The entire cycle is then repeated automatically.

In test operations at the BCR laboratories, performance data have been collected on the gas consumption, capacity, and reliability of the system. In these tests, the unit was operated routinely, injecting coal at rates up to 800 lb/hr into a receiving vessel pressurized to 1,400 psi.

For the 5 ton/hr pilot plant, it is planned to install two piston feeders, each with a capacity of 2.5 ton/hr. In addition, the layout for the pilot plant will provide for the installation of an alternate lock-hopper system to deliver coal to the high-pressure coal feed tanks represented as F-4 in Figure 6. Thus, in the event extended development work on the piston feeder is required, operation of the gasification plant can be sustained by means of the lock hopper-feed arrangement.

Various designs of feeders for delivering the coal from the high-pressure receivers to the transport lines to the gasifier are being studied. Tentatively, it is planned to use a specially designed screw feeder for this application, but further development work and testing of feeders is required to establish the most suitable feeder for this purpose. Process gas will be used for the transport medium and, at pressures of about 100 atm, the weight ratio of coal to gas will be about 8:1.

C. Coal Gasification

As stated in the general description of the pilot plant, the gasifier will be an oxygen-blown, two-stage unit designed for coal feed rates up to 5 ton/hr and a maximum operating pressure of 1,500 psi. The unit will be adaptable to all ranks of coals.

The outside diameter of the gasifier is 5.5 feet, and the diameter inside the refractories is 3 feet. The heights of Stages 1 and 2 are 6 feet and 14 feet, respectively, and the height of the slag quench and removal section is 13 feet. Velocities in each stage will vary with changes in feed rate and operating pressure. The expected minimum gas velocities for Stages 1 and 2 are 0.27 ft/sec and 0.15 ft/sec, respectively; corresponding maximum residence times are 24 and 73 seconds. The expected maximum velocities are 2.3 and 1.12 ft/sec for Stages 1 and 2, respectively, and the corresponding minimum residence times are 2.9 and 9.8 seconds. The gas exit temperature will be about 1700 F and, as shown in Table 1, the composition of the gas will be approximately 16 percent carbon dioxide, 28 percent hydrogen, and 7 percent methane, with the balance being water and less than 1 percent each of nitrogen and hydrogen sulfide.

A simplified process flow diagram with major flow rates and operating conditions for a coal feed rate of 5 ton/hr is shown in Figure 7. A material balance is given in Table 2.

Dry, pulverized coal, conveyed with steam, is fed into the upper stage (Stage 2). The coal is devolatilized and partially gasified in Stage 2 by the steam and the hot gases and char rising from the lower reaction zone (Stage 1).

TABLE 1. GAS STREAM COMPOSITIONS FOR OXYGEN-BLOWN TWO-STAGE SYSTEM
(Volume Percent)

Component Gas	1 Gasifier Product	2 CO-shift Feed	3 Acid Gas Removal Plant Feed	4 Acid Gas Removal Plant Product	5 Final Pipeline Gas
CO_2	16.25	12.52	31.06	0.23	0.63
CO	23.60	18.19	14.63	21.37	0.11
H_2	28.41	21.90	45.00	65.72	4.79
CH_4	7.04	5.43	8.07	11.79	92.36
N_2	0.45	0.35	0.52	0.76	2.11
H_2S	0.55	0.43	0.63	0.00	0.00
H_2O	23.70	41.18	0.09	0.13	0.00
Total	100.00	100.00	100.00	100.00	100.00

TABLE 2. MATERIAL BALANCE FOR 5 TON/HR OXYGEN-BLOWN TWO-STAGE GASIFIER

Input	Weight, lb/hr	
Stage 2		
Coal	10,000	
Transport Gas Recycle	(1,919)	
Steam	8,774	18,774
Stage 1		
Char Recycle	(9,408)	
Steam Feed Gas Recycle	(275)	
Steam	2,880	
Oxygen (99.5%)	6,361	9,241
Total Input		28,015
Output		
Stage 2		
Raw Product Gas	27,331	
Recycle Gas	(2,194)	
Recycle Char	(9,408)	27,331
Stage 1		
Slag	684	684
Total Output		28,015

The products leaving the gasifier are first cooled; the entrained char is then separated from the gas, collected, and reinjected with oxygen and additional steam into the Stage 1 reaction zone.

Molten slag formed in Stage 1 drops through a water spray into a reservoir of liquid water below. The resulting granulated slag particles are periodically removed through a lock hopper system.

D. Waste Heat Recovery and Char Recycle System

Details of the waste heat recovery and char recycle system are shown in Figure 8. By means of a heat exchanger, essentially a waste heat boiler, and direct water sprays, the temperature of the char and gas will be decreased to about 900 F. A multi-cyclone unit will be used for separating the char from the gas. By sequential operation of lock hoppers, the char is dropped by gravity into the gasifier char feed bin.

Similar to the situation with coal feeders, various types of char feeders are being investigated. Present plans for feeding hot char to Stage 1 are to use an arrangement of a rotary valve at the base of the feed bin to deliver char into a standpipe which in turn will feed a specially designed screw feeder. Maintaining a uniform head of char with uniform bulk density on the screw feeder facilitates the problem of maintaining uniform feed rates. The gasifier will be equipped with three reactant or char burning nozzles. Each nozzle will be equipped with a separate feed system.

About 95 percent of the char will be returned by the multi-cyclone. Approximately two-thirds of the char entering Stage 1 is gasified and about one-third is recycled. Thus, about 1.6 lb of fixed carbon is recycled to Stage 1 for each pound of fixed carbon entering with the coal in Stage 2.

The gas, with finely dispersed char, passes from the multi-cyclone to a second heat exchanger, steam generator, where the gas temperature is reduced to 650 F in preparation for the carbon monoxide shift reaction. After the heat exchanger, the gas is filtered to remove the fine char. Currently, a sand bed filter is under investigation for the removal of fine char. If successful, it will eliminate the need for further cooling of the gas and subsequent reheating for the CO shift. If solid bed filters are unsatisfactory, it may be necessary to resort to bag-type filters which presently require gas temperatures below 500 F, or to wet scrubbing which will lower the gas temperature even further. In either case it would be necessary to reheat the gas prior to the CO shift.

The char recycle system will provide for either returning the fine char to the gasifier char feed bin or for removing it from the system.

E. Carbon Monoxide Shift

The purpose of the carbon monoxide shift conversion is to adjust the hydrogen to carbon monoxide ratio in the gas to 3.1 to 1 as required for the methane synthesis. As shown in the simplified process flow diagram, Figure 9, the facilities will include catalyst guard filters, reactors, and the appropriate heat exchangers.

Gas from the heat recovery and char removal system will be fed to the CO shift facility at a temperature of 650 F and a pressure of about 1000 psi. In the catalyst guard filters, any olefins in the gas will be hydrogenated; sulfur compounds such as carbonyl sulfide will be converted to hydrogen sulfide; and any fine char remaining in the gas will be trapped. By providing two units, the catalyst in the off-stream unit may be regenerated with steam and air.

Superheated steam will be added to the gas entering the reactors to adjust the steam to dry gas ratio to 0.7. Composition of the feed gas to the reactors is shown in Table 1. The extent of reaction and thus the hydrogen to carbon monoxide ratio of the exit gas stream will be controlled by appropriate settings of the following operating conditions: (1) the steam/gas ratio, (2) the amount of gas bypassed, and (3) reactor inlet gas temperature.

For the 5 ton/hr pilot plant it is expected that the bypass stream will be about 40 percent of the feed gas and that 95 percent of the carbon monoxide in the remaining 60 percent will be converted to hydrogen and carbon dioxide.

The exothermic heat release from the reaction will raise the gas temperature from 650 F to about 865 F. After mixing the converted gas with the bypass stream, the gas is cooled to 95 F. The composition of the mixed gas stream, having a H_2/CO ratio of 3.1, is shown in Table 1.

F. Acid Gas Removal

From a study of some 35 available acid gas removal processes, it was concluded that the criteria established for the BI-GAS process were best satisfied by those processes employing an organic solvent as the stripping medium and which selectively remove the hydrogen sulfide and carbon dioxide. Such processes include the Purisol, the Rectisol, and the Selexol.

Figure 10 is a simplified process flow diagram of the acid gas removal and sulfur recovery based on the Purisol process and a Claus unit for recovery of elemental sulfur.

The gas from the CO shift converter will first pass through an absorber where the hydrogen sulfide will be absorbed in N-methyl-2-pyrrolidone. The hydrogen sulfide will be steam stripped from the solvent in a separate tower and fed to the Claus sulfur recovery plant. The solvent will be recycled. The process gas from the hydrogen sulfide absorber will pass through a second absorber where the carbon dioxide is absorbed. The carbon dioxide will be stripped from the solvent in a separate vessel and vented to atmosphere; the solvent is recycled.

To satisfy pipeline gas specifications the hydrogen sulfide content of the gas must be below 0.25 grain per 100 scf. The composition of the gas leaving the acid gas removal section is shown in Table 1.

G. Methanation

The most advanced designs of methanation processes - that is, the conversion of carbon monoxide and hydrogen to methane, are based on fixed-bed catalytic reactors. However, in the interest of furthering research in this area, current laboratory work is directed toward development of a methanation system based on a fluidized-bed catalytic reactor.

A simplified process flow diagram of the methanation step based on using a fluid-bed reactor is shown in Figure 11.

The methanation reaction is highly exothermic, and temperature control is critical. Below 500 F the carbon monoxide reacts with the nickel catalyst to form nickel carbonyl, resulting in loss of catalyst and the production of a hazardous gas. Above 500 F carbon formation occurs by the reaction of hydrogen with carbon to form water and elemental carbon, resulting in a decrease in yield.

The fluid-bed reactor should provide for better heat transfer than is possible with fixed-bed reactors. With sufficient cooling coils and heat exchange capacity, the exothermic heat should be controllable at higher levels of carbon monoxide concentration in the feed gas than is now possible.

The temperature of the feed gas will be in the range of 550 to 625 F. In the pilot plant, provisions will be made to introduce the feed gas at three levels to permit distribution of heat. (See Figure 11.) With the appropriate arrangement of cooling coils and heat exchangers, it is expected that process gas containing about 20 percent carbon monoxide can be fed directly to the methanator.

The final pipeline gas, having a gross calorific value of about 950 Btu/scf, will have a composition as shown in Table 1.

IV. GENERAL FACILITIES

The research facility now being planned, requiring approximately 25 acres, is to be located near U. S. Highway 119 just north of Homer City, Pennsylvania, not far from the BCR research center at Monroeville, Pa. The facility would be laid out to accommodate the proposed experimental systems plus general utilities. Space for expansion would also be provided, especially in the gas processing area.

Water for cooling purposes, steam generation, and fire protection will be supplied from Two Lick Creek which borders on the plant property. Utilization of this water will require installation of facilities for pumping, cooling, filtering, and chemical treatment. City water will be available for limited required uses.

In a commercial plant, steam requirements may be satisfied by use of heat exchange equipment in the gas treatment section of the plant. However, a steam boiler will be provided for the pilot plant to assure operation of the gasifier exclusive of the gas treatment facilities.

Adequate electrical power will be furnished to the plant so no generating equipment is required. The necessary substation and motor control rooms will be installed.

Buildings will be provided for office, laboratory, maintenance, and other services as required. Miscellaneous facilities will include roads, parking lots, communication system, etc. All effluents will be treated and all waste products collected to eliminate environmental pollution.

V. SUMMARY

The design characteristics of a fully integrated coal-to-pipeline gas pilot plant based on the BI-GAS process have been delineated. At the present time, these are being incorporated in an engineering bid package scheduled for completion in October, 1971. With appropriate funding, procurement and erection of a 5 ton/hr pilot plant on the site at Homer City, Pennsylvania, may be reasonably expected to be completed by early 1974.

ACKNOWLEDGMENT

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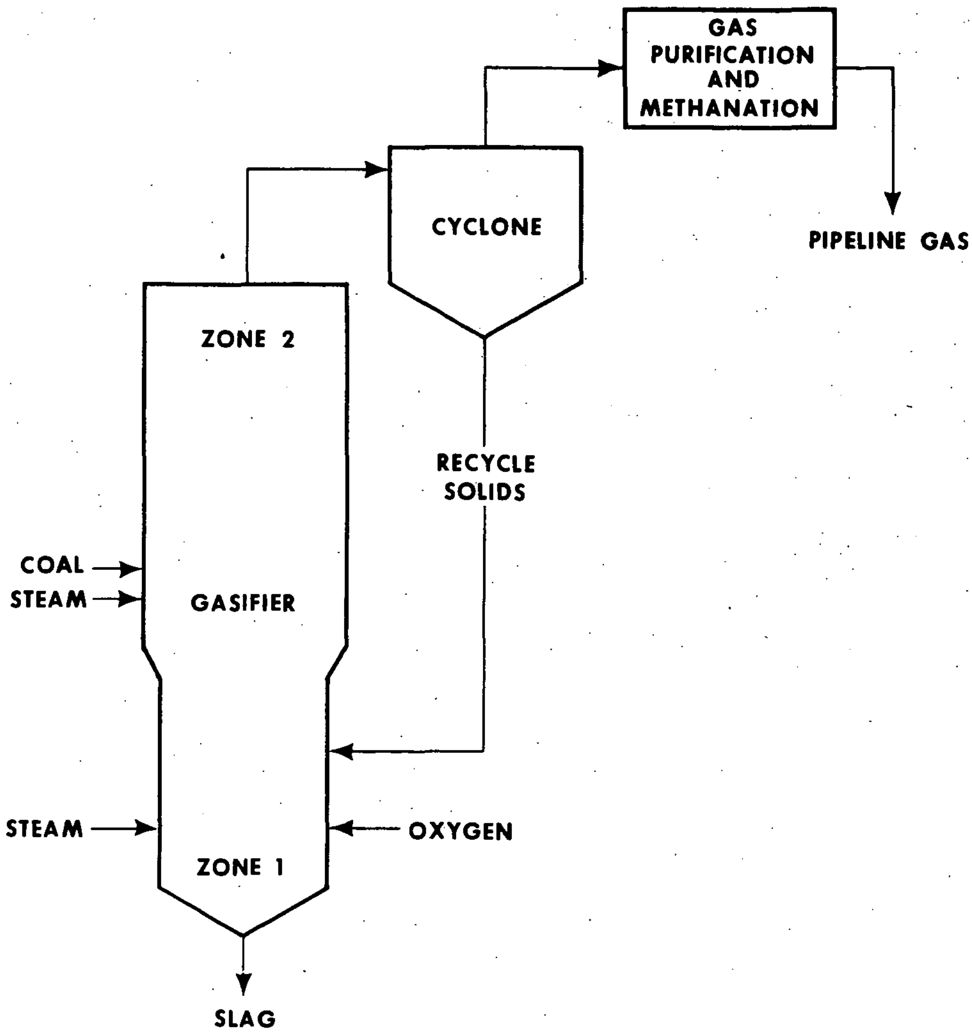

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Figure 1. Simplified Flow Diagram for Two-stage Super-pressure Gasifier

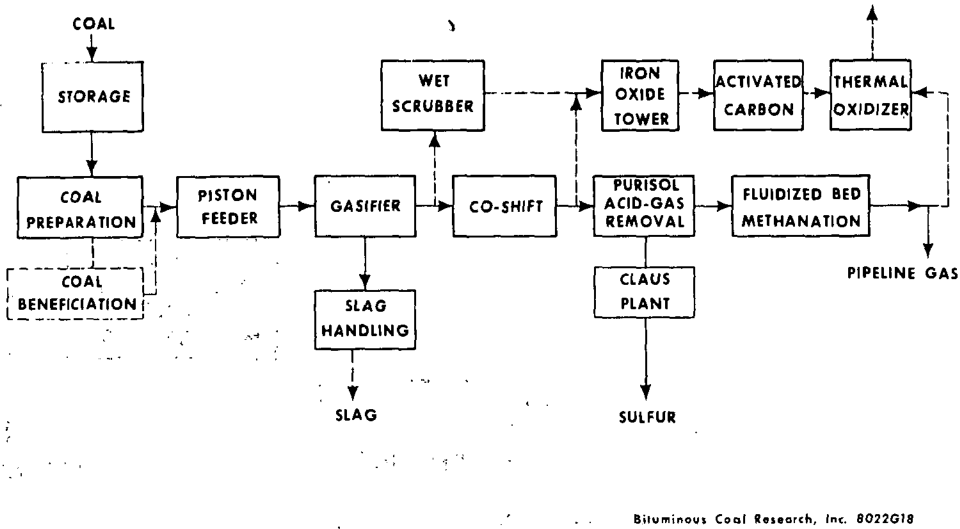

Figure 2. BCR/OCR BI-GAS Pilot Plant Flow Diagram

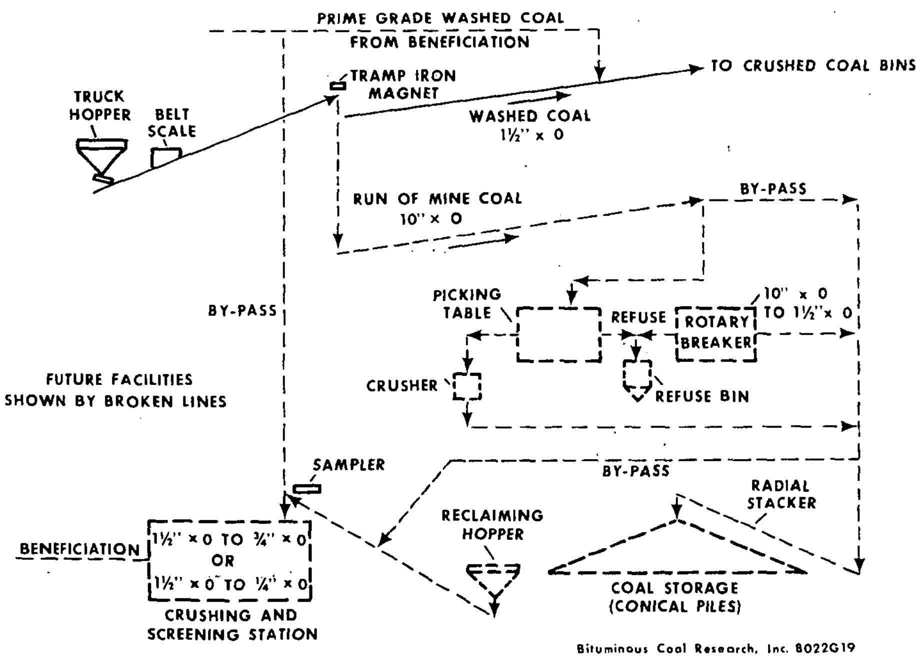

Figure 3. Coal Handling and Storage System Flow Diagram

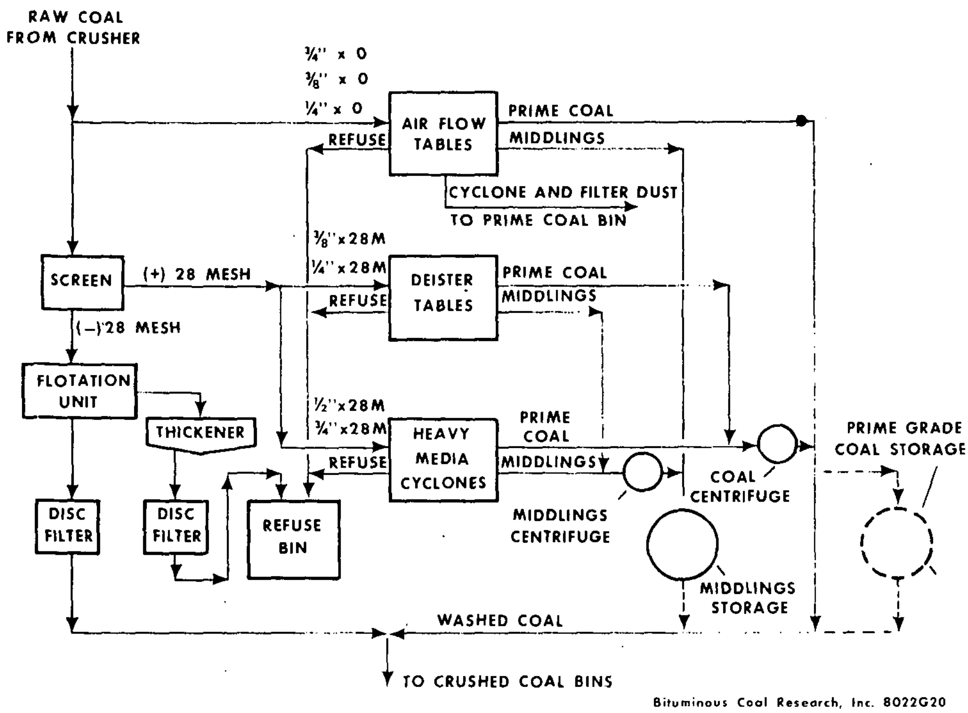

Figure 4. Coal Beneficiation Flow Diagram

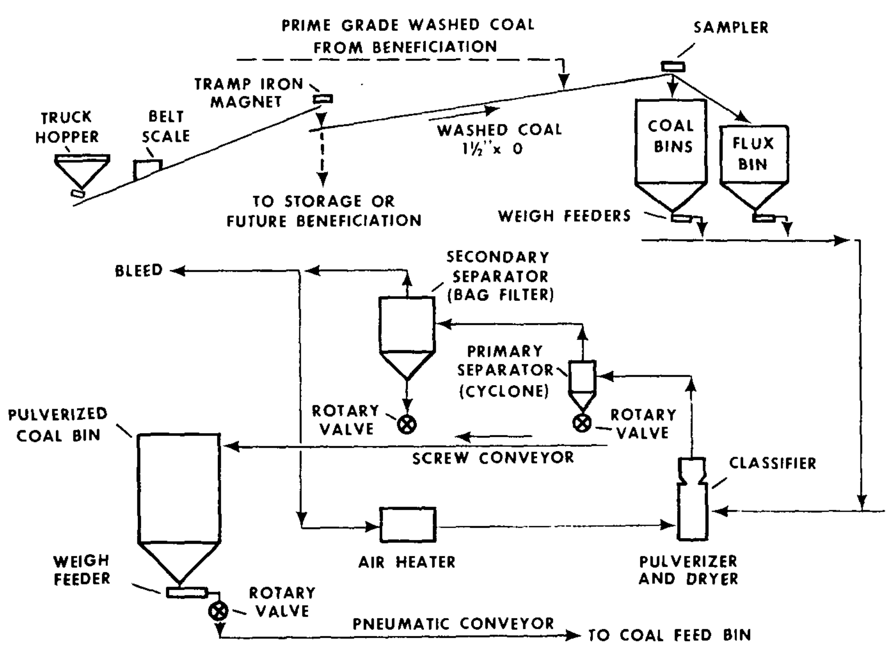

Figure 5. Coal Handling and Preparation System Flow Diagram

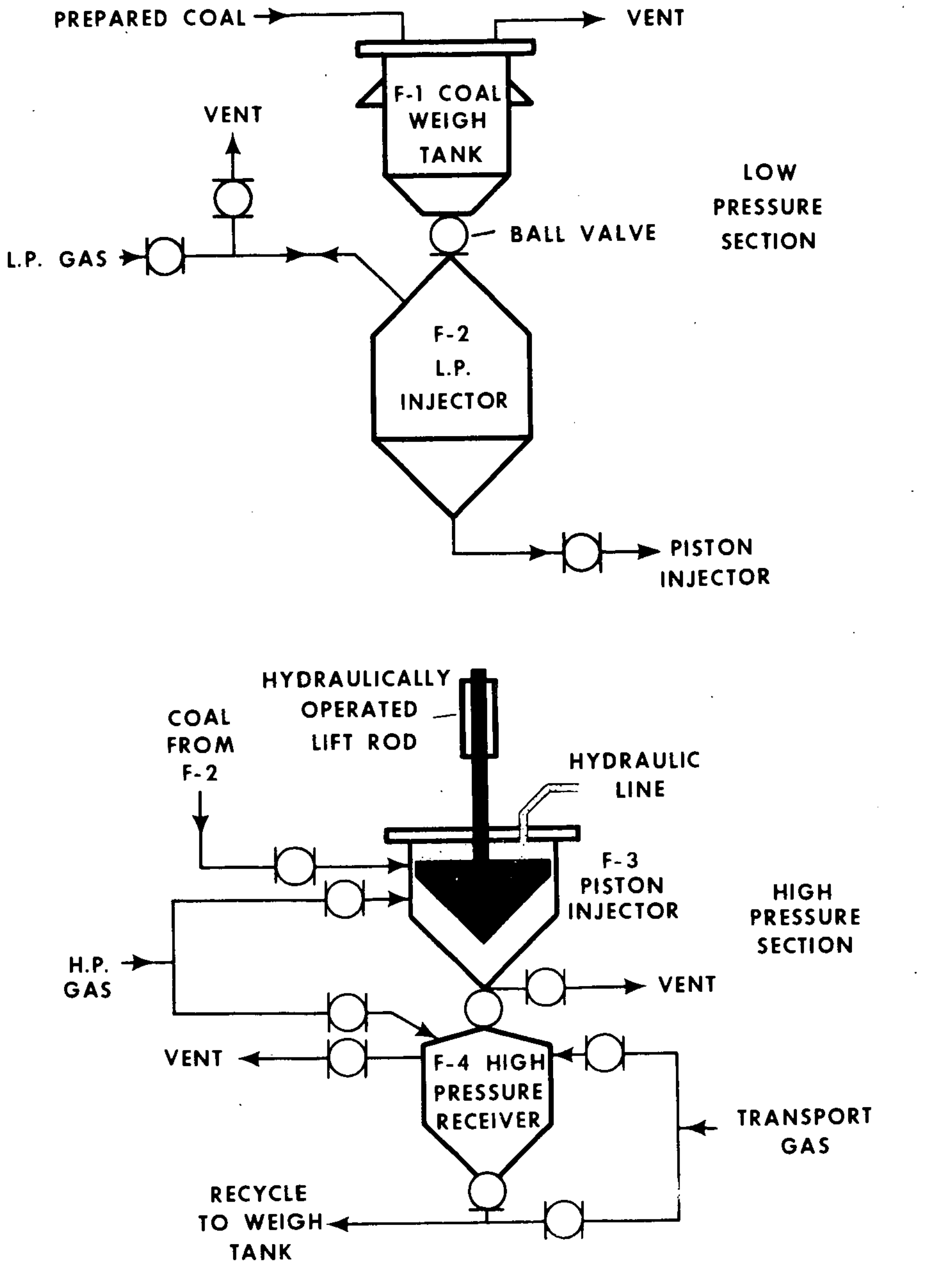

Figure 6. Piston Feeder Diagram

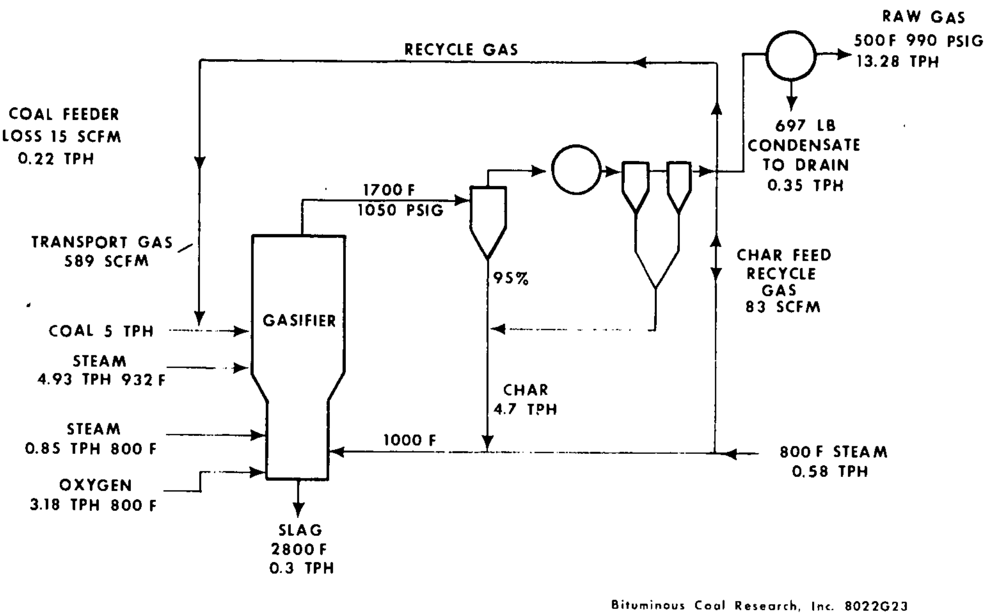

Figure 7. Process Flow Diagram for 5 TPH Oxygen-blown Two-stage Gasifier

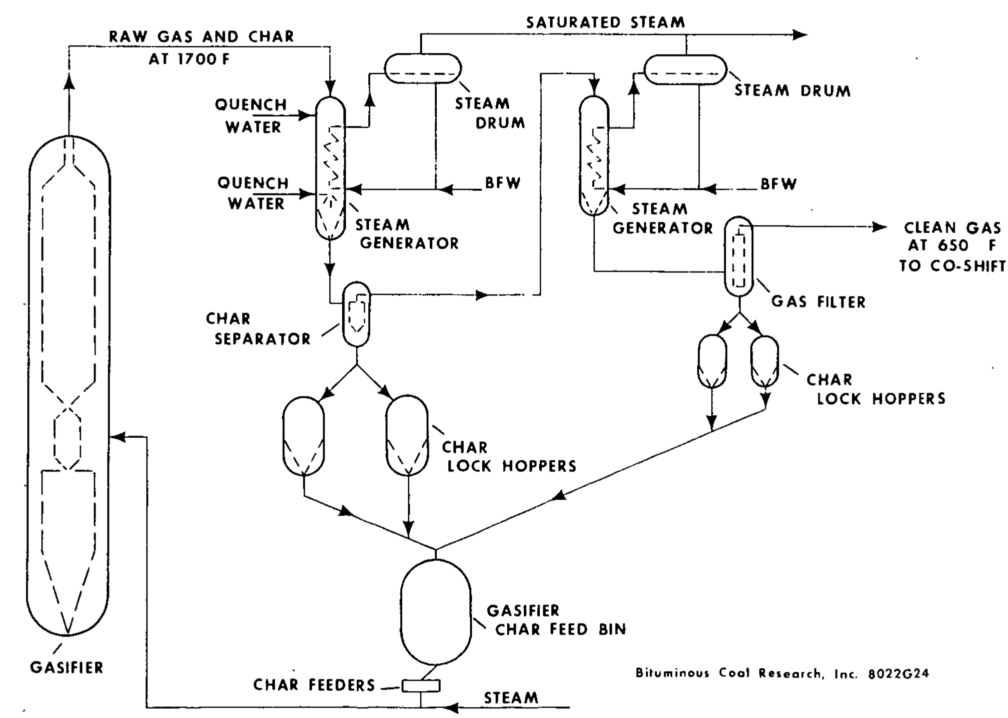

Figure 8. Waste Heat Recovery and Char Recycle Flow Diagram

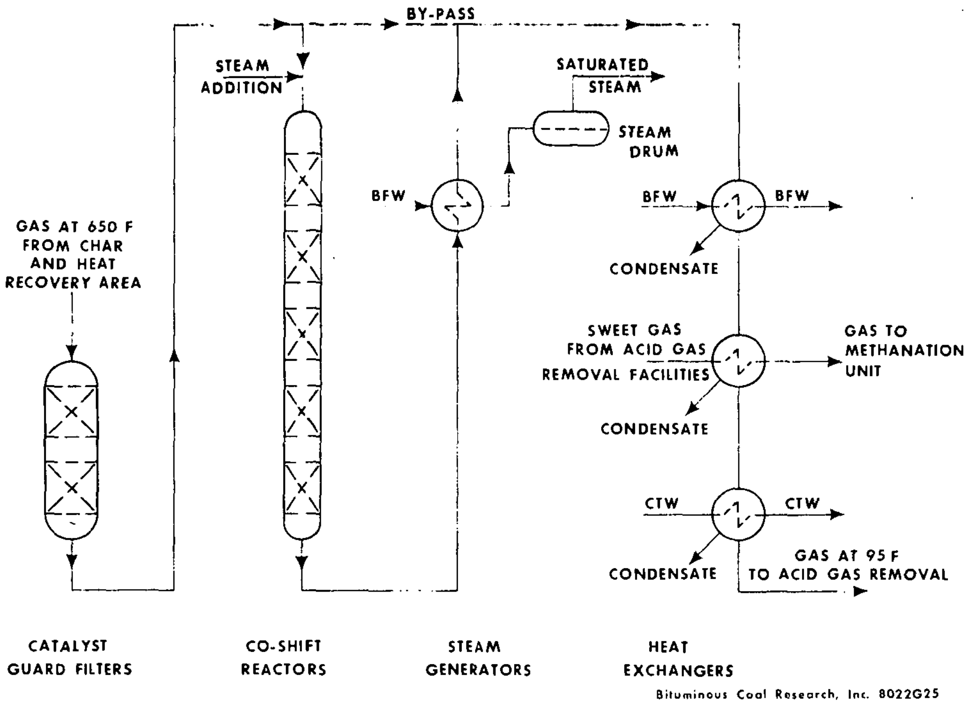

Figure 9. CO-shift Flow Diagram

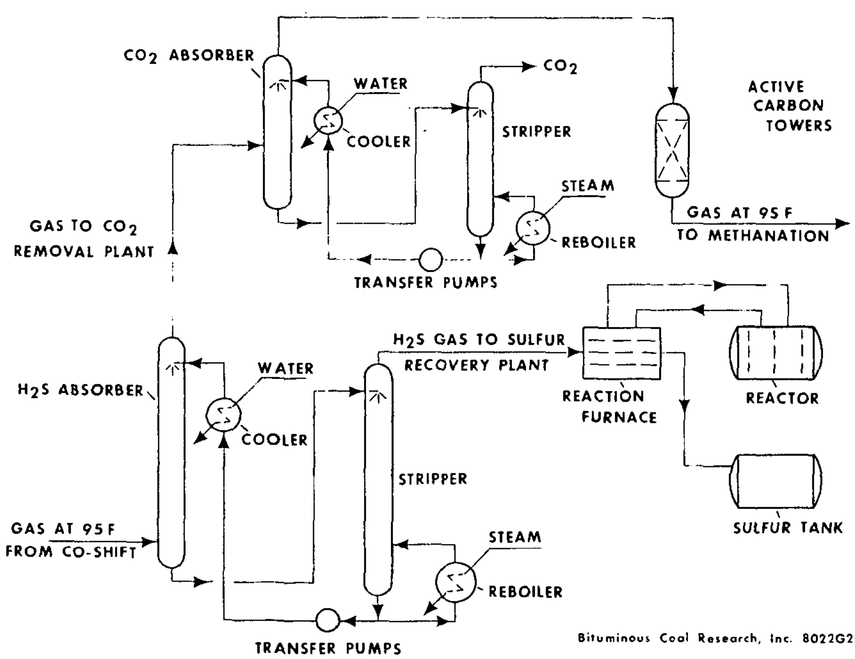

Figure 10. Acid-gas Removal and Sulfur Recovery Flow Diagram

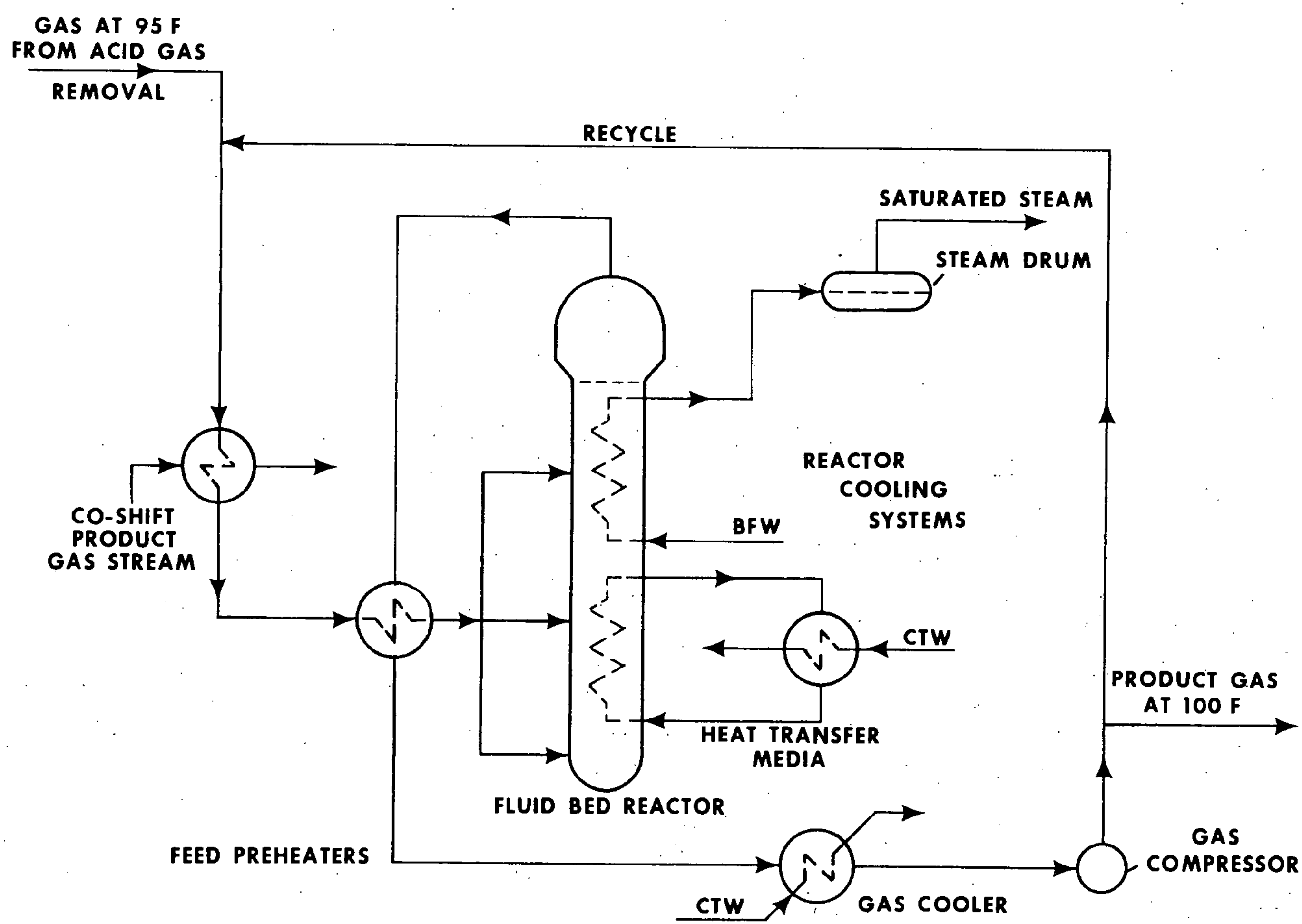

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Figure 11. Methanation Flow Diagram